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SOME NOTES ON REGENERATION AND REGULATION IN PLANARIANS.

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I. THE SOURCE OF MATERIAL OF NEW PARTS AND LIMITS OF SIZE.

MANY observers have noted the tendency of planarians kept without food to diminish in size. My attention was specially directed to this phenomenon by some experiments undertaken to test the effect of external conditions on the regeneration of *Planaria maculata.* I had already studied the effect of temperature on the regeneration of this form in conjunction with Mr. Knowlton.[1] I next undertook to test how far the chemical constitution of the medium affected the rate and form of regeneration. As an introduction to the systematic study of this subject, I made some experiments to determine whether any of the substances dissolved in the water of the habitat is necessary for regeneration. For this purpose I redistilled some of the ordinary distilled water of the laboratory, using flasks of Jena glass to get rid of the minute traces of copper found in water from copper stills. Permanganate of potash was dissolved in the water in the Jena flask to destroy traces of organic matter, and the distillate was again distilled in the same manner to insure the greatest possible degree of purity. The redistilled water thus obtained was carefully oxygenated by running a stream of air through it.

The pieces of planarians used for the experiments were washed in this water and then transferred to more of the same; the vessels (cleaned in strong acid) and water were changed frequently to get rid of any traces of bacterial growth. I soon found that under these circumstances regeneration went on as rapidly and as well as in tap water or the water of the habitat; thus demonstrating that the substances contained in these waters were not necessary for regeneration.

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[1] Lillie and Knowlton. The Effects of Temperature on the Development of Animals, *Zoöl. Bull.*, vol. i.

However, the decrease in size already mentioned was so rapid and marked as to appear to deserve special study. So I isolated a number of active planarians in the redistilled water, measured them, and kept them in a thermostat at temperatures that ranged from 20° to 27° C. The dishes and water were changed regularly and frequently, measurements of each individual being made at the same times. The table on the opposite page shows the history of these specimens; less than half of the actual measurements in this series are given.

It will be noted that the rate of decrease was not the same in all; in 2, for instance, it was much more rapid than in the others. This is probably due in part to greater activity of 2. Nor is the rate perfectly uniform in any given specimen, probably owing to variations in the temperature and in activity at different times.

The smallest specimen obtained (No. 5, after 43 days) was certainly less than one-hundredth the bulk of the original animal. Its length was one-fifteenth the original length, its width one-third the initial width, and if we suppose that its dorso-ventral diameter was reduced by only one-half, the bulk would be one-ninetieth of the original bulk. But there can be little doubt that its dorso-ventral diameter was reduced more than one-half.

Increase by fission was entirely stopped, but, on the other hand, the power of regeneration remained. Thus, when No. 5 had been reduced to less than one-half its original length, it was cut in two parts, and both regenerated completely, *although with constant diminution in bulk.* The same experiment succeeded in No. 3, after it had been starved to less than one-fourth its original length.

It is thus demonstrated that from a given individual one of less than one-hundredth the original bulk may be produced by appropriate means. This constitutes a criticism on those experiments that have been made to determine the limits of regeneration in planarians by direct operation. The possible

DAYS.	1.	2.	3.	4.	5.
1	7 × .7	7 × .5	10 × 1	6 × .5	9 × .75
5	7 × .7	5.5 × .5	7 × 1	6 × .5	8 × .75
12	6.5 × .5	4 × .33	6 × .66	Dead.	5 × .5
17	6 × .5	4 × .33	5 × .4		4 × .3
23	4 × .5	2.5 × .5	4.3 × .5		3.25 × .3 Cut in two.
25		Cut in two.			1.75 × .3 (head) 1.25 × .3 (tail)
27	3.7 × .4	1.25 × .3 (head) Partial regeneration. Died.	4 × .4		1.75 × .3 (head) 1.25 × .3 (tail) Partial regeneration.
33	3 × .4		3 × .4		1.4 × .3 (head) .9 × .3 (tail) Complete regeneration. Anterior piece died two days later.
40	2.3 × .4		2.7 × .4		.6 × .25
43	1.9 × .4 Cut in two. Parts died in two days.		2.25 × .4 Cut in two. Tail end, 1.1 × .4; regenerated in four days (partly). Head end, .9 × .4; regenerated very little new tissue.		.6 × .25 Lost by accident.

Table giving history of five planarians in distilled water. The vertical columns should be read separately. There is a slight discrepancy in the measurements of 2 and 3 for 17 and 23 days, no doubt due to an error in observation. The column to the left gives the number of days from the beginning of the experiment. The measurements, made after 17 days with the ocular micrometer, have all been reduced to millimeters.

limits of regeneration have been found by such experiments to be not much less than one-sixteenth of the bulk of the original animal. That a much lower limit has not been found is due partly to the extensive exposure of internal tissues along the cut surfaces, and partly (perhaps) to limitation of variety of tissue, but certainly not, it would appear, to deficient size.

Do all organs suffer equally in the reduction? It might be expected that the organs of reproduction would suffer first, as they do not contribute to the life of the individual; but the specimens used in the experiments were not sexually mature, so this point was not settled. The other systems of organs were reduced in apparently similar proportions. Thus the intestinal diverticula in 5 were reduced to five on each side, and the branches of the longitudinal nerves were apparently equally reduced.

Does the reduction affect chiefly the size or the number of the cells? A careful histological study would be necessary to answer this question in detail. Not having made this, all that I can say is that the branched pigment cells lying near the surface, that are readily visible under a low magnification, are reduced to very few, but their size is not noticeably affected.

Do the processes of reduction retrace the steps of normal growth and development? I think that this question must be answered in the affirmative. Certain it is that specimens reduced by starvation to a smaller size than just hatched specimens of the same species resemble these in their general proportions, the relatively greater breadth in proportion to length as compared with mature specimens, the smallness of the cephalic lobes, and in the small number of the intestinal diverticula and branches of the longitudinal nerves. It would be interesting to determine whether or not these artificial embryos, as they might be termed, could under favorable circumstances repeat the steps to the mature and fully grown condition from which they were reduced. I see no reason to doubt that this is possible.

In regeneration, under the circumstances of these experiments, two processes are taking place side by side; not only is new tissue being formed at the cut end, but the old tissues are undergoing a translocation and partial redifferentiation to accommodate themselves to the new proportion that must be assumed. The new tissue at the cut end must be formed entirely from the old tissue, and the final result involves, therefore, an extensive working over of the old material. The original tissues, with constant losses, owing to destructive metabolism, are moulded into the form of a new individual. In trying to form a mental image of the forces at work in this complex rearrangement, one can think only of an "internal mould" (an expression of Buffon to which Professor Whitman has called my attention). No less remarkable is the maintenance of form in individuals that gradually waste away to one-hundredth part or less of their original bulk. Such individuals in all stages of reduction appear normal in all respects, physiologically as well as morphologically. They are active and exhibit perfectly normal reactions, showing no indications of sickness.

VASSAR COLLEGE, Jan. 4, 1900.